smartrail 4.0

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Feasibility Study FRMCS

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	Author	Checked	Approved
Surname, first name	Daniel Grünig	Alex Brand; Robert Badertscher; Marcel Kicken and Patric Pellet Stefan Mauron	Robert Badertscher;
Name of company	SBB	SBB Ericsson Swisscom	SBB

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Contents

1 Introduction

At present, communications related to rail operations from and to trains are carried out via the Global System for Mobile Communications - Rail (GSM-R). GSM-R is the basis for train monitoring and train control and for voice communication between traffic controllers and train drivers. It is also used for operational support activities such as installation monitoring, process support (for example, GSM-R-based train dispatching) and customer information.

The basic GSM technology was developed in the 1980s, introduced into service from 1991 and will only be supported by public mobile phone providers for a few more years. Industry will probably still support GSM-R into the 30s.

Because connectivity requirements will increase significantly in future as a consequence of digitalised railway production, the project "Connectivity" is intended to ensure high-performance and reliable mobile radio connectivity for future railway operations. The project will focus on bandwidth, capacity and availability. The Future Railway Mobile Communications System (FRMCS) is to be based on the same 5G technologies as the public mobile radio communication systems and is to replace the old "GSM-R" system.

A decision on the way forward for the development and rollout of connectivity is to be taken based on the concept for Connectivity in 2021. The following aspects are its central features:

- A decision in principle on collaborative arrangements / sharing for the construction of the network
- The essential architecture for the access network and the corresponding number of items such as base station sites required.
- A decision in principle on value creation depth with regard to construction and operation

As regards the relevant concept development, we essentially distinguish between the following sub-concepts:

- FRMCS network
- Transport network
- Vehicle architecture

2 The need for a feasibility study

In terms of its functional, technical and operational requirements, the scope of FRMCS exceeds the scope of a public mobile phone network. Whereas the 5G standard will be developed through global collaboration by standardisation committees (3GPP – 3rd

Generation Partnership Project), the additional railway-specific aspects will be standardised at UIC/ETSI TC-RT level (in order, for example, to meet the interoperability requirements).
Before FRMCS is introduced into service on the Swiss railway network, it must meet European standards. The European Rail Agency for Railways (ERA) must embed this standardisation within the framework of the Technical Specification for Interoperability / Control and Command Signalling (TSI/CCS) by 2022.
Since standardisation has not yet been fully carried out, the general regulatory and technical parameters are also not yet fully known. Moreover, the introduction of 5G technology is in its infancy and many of the functions needed for mobile phone coverage along railway lines are still at the development stage (e.g. mobility).
So as to address the relevant challenges, smartrail 4.0 and its partners (public providers and mobile phone equipment suppliers) are giving detailed consideration to various conceivable scenarios covering cost/benefit, feasibility and strategic fit. The aim is to develop the largest possible morphological box (solution space), assess the individual components in the box and, where necessary, to theoretically test them as a **feasibility study** partly linked to field tests (PoC).
Once the general parameters have been determined, some of the morphological box's potential solutions will be abandoned as no longer feasible. It is therefore all the more important during the current phase to create the widest possible solution space so that only workable solutions remain after the scope of the general parameters has been finally narrowed down.

In addition to questions about the technical, operational and economic feasibility of FRMCS and about the timing of its introduction, the following questions also require answers:

- Assuming complementary implementation (FRMCS by railway companies, 5G by public mobile phone providers), to what extent can any synergies be exploited?
- To what extent it is possible for different signals to affect each other and can malfunctions be prevented/minimised by joint planning/implementation?

The figure below illustrates the relationship between these open questions and those analyses which have been carried out or are still at the planning stage (PoCs):

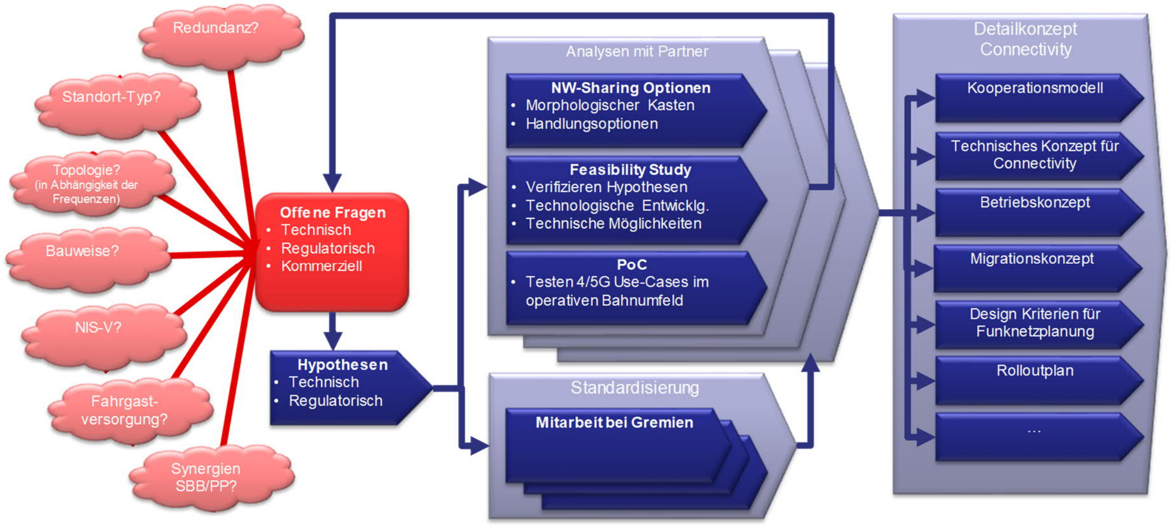

Figure 1: Relationship between open questions and the analyses being undertaken

Three topic areas - **"Network Sharing Options"** (collaborative models), **"Feasibility Study"** (theoretical and simulated feasibility studies) and **"Field tests"** - are being worked through partly in parallel and over several iterations.

This feasibility study is aimed primarily at the FRMCS network and, at the margins, at what such a network requires of a transport network. It corresponds to the "Feasibility Study" box in the figure above.

<u>Delimitation:</u>

All other chapters of this report and the contributions of Ericsson and Swisscom exclusively deal with the "Feasibility Study" but not with the activities NW-sharing Options or PoC.

3 Scope and organisation of the feasibility study

The concept for the Future Railway Mobile Communication System (FRMCS) Service for smartrail 4.0 applications and for the lifecycle replacement of GSM-R as the central element of SBB's rail communications system require key technical questions as to the feasibility of the project to be clarified in advance. The highly novel technical concept of employing 5G mobile phone technology for railway communications, the complexity of integrating it into the overall "SBB railway communications" system, together with service migration are the three drivers behind the need for clarification.

Since an "outside perspective" of railway communications for SR40 and for SBB Telecom will provide invaluable support, the feasibility study has been commissioned from an external source. The aims of the study were jointly defined by SR40 and SBB Telecom. Within the framework of SR40, SBB Telecom will be managing the conduct of the study in order to ensure that railway requirements and the aspect of "co-existence with the current GSM-R mobile communications system" is guaranteed. Experience of operating a 4G network (which most closely matches 5G) and the innovation and rollout of 5G technology are the key requirements for this feasibility study. Both aspects can be covered best by awarding the contract to a network operator and a system provider. Based on a publicly announced invitation to tender Swisscom AG (Operator) and Ericsson AG (System Provider) were contracted by separate mandates. Their tasks include theoretical analyses, possible scenarios for specific isolated aspects of a mobile network but not an entire network concept and software-based simulation for "Radio Network Planning" in particular. SR40 will publish the results and make them freely accessible.

3.1 Topic areas:

- Determining the definitive design criteria (Availability, Accessibility, Retainability) for constructing and maintaining a future mobile communication network (Core; Access; Transmission) for the railway and for passenger communication.
- Defining the network structure(s) on the basis of the design criteria, focusing on the access network and antenna locations (taking into account technological developments as regards radiation elements and active elements at antenna sites).
- Transferring the existing GSM-R network to new network structures, incl. services and service platforms plus appropriate QoS requirements yet to be defined.
- Co-existence considerations: GSM-R, radio technology for FRMCS and public mobile phone networks.
- Demonstration on a reference section of track
- Radio network predictions for the reference section of track
- Considerations relating to non-ionising radiation (NISV) (with the assistance of "NISV-QS", i.e. of the quality assurance system for complying with the Swiss federal ordinance on non-ionising radiation NISV) as regards implementing the defined network structures.

The study will be undertaken as an iterative process in order, on the one hand, to allow interim findings from PoC testing and other sub-projects (e.g. architecture and technology as well as cooperation models) to be incorporated and in order, on the other hand, for the feasibility studies to take into account questions which arise from other sub-projects as the work progresses. Three phases are needed in total. As far as we can tell at present, the task can then be regarded as completed.

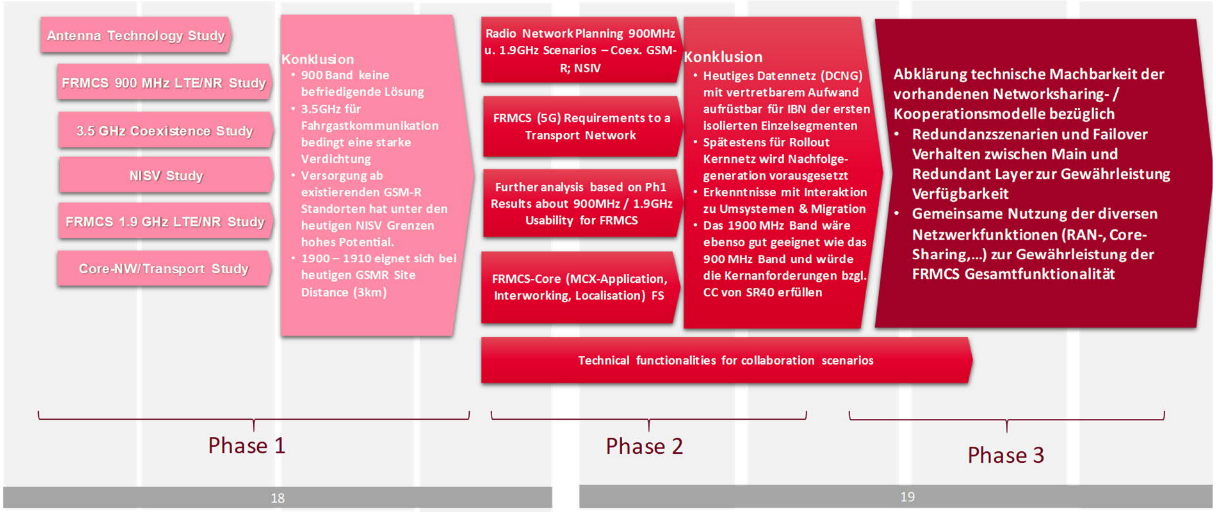

Figure 2: The "FRMCS Feasibility Study" action plan

4 Results and Conclusions

Following completion of the 3rd phase, the feasibility study was completed at the end of 2019. The studies undertaken by the contractor were jointly assessed and smartrail 4.0 brought all the phases to an end by adding its own conclusions.
The conclusion of the 3rd phase was integrated into a variant study for the provision of mobile radio communications in the rail network (Trackside Deployment Architectures).

4.1 Companies involved in each phase

- Phase 1: Swisscom, Ericsson and SBB
- Phase 2: Ericsson and SBB
- Phase 3: Ericsson and SBB

4.2 Conclusions after the 1st phase

The following topic areas were considered and examined in the 1st phase.

Work package	Conclusion
Radiation elements	• Active and beamforming antennae can only offer slight benefits if used with those frequency bands in the 900 MHz and 1900 MHz range which are under consideration. Consequently, coverage will probably continue to be provided using passive antennae.
Suitability of the 900 MHz band for FRMCS	• FRMCS with 5G-NR can only be realised in the 900 MHz band if: ○ the **entire ER band plus part of the GSM-R spectrum could be utilised**, to make available the minimum 5G bandwidth of 5MHz.

Work package	Conclusion
	○ special 5G functions could be used to provide support. However, it is not yet clear whether this will be included in the official specification. • FRMCS with LTE (1.4 MHz and 3 MHz bandwidth) in the 900 MHz band ○ Even with the shortest site distances, the 1.4 MHz solution only just allows 1 MB/s data throughput which, according to the SR4.0 requirement, is not adequate. ○ In principle, the 3 MHz variant would, on first consideration, be sufficient to provide simple coverage. Since the EU Radio Spectrum Committee (RSC) decided to use the lower range of the ER band for short range devices, this variant drops out of contention if no purely national solution is sought; which would then in turn be disadvantageous in the areas bordering the EU. ○ In addition to its physical limitations, 4G/LTE will be an old technology when FRMCS is rolled out. **The main finding from the 1st phase of the feasibility study was that the 900 band is not a satisfactory solution for FRMCS.**
Combining and co-existing with the 3.5 GHz public provider network	• Using 3.5 GHz for passenger communication requires greater network density compared with today • Making it feasible within the rail corridor is difficult because the signal needs to penetrate into the vehicles to reach passengers. Whether deflecting the signal using mirrors (scattering panels) in conjunction with RF windows would be effective will be included in PoC testing and reported on. • If data rates of >> 100MB/s have to be attained, the other 4G and 5G frequencies (i.e. without 3.5 GHz) will not be sufficient. Even with the greatest transmission power being considered, only 80 to 100 MB/s per provider are possible at a 3km site distance. • Depending on the trackside architecture for FRMCS (with respect to redundancy solution for radio coverage), there will be different requirements about inter cell distance for passenger communication and for rail communication. Consequently, the synergy effect will be rather modest.
NIS consideration	• Providing coverage from existing GSM-R sites has great potential within the present NISV limits, since these limits have not yet been fully exploited at most of the purely GSM-R sites.

Work package	Conclusion
	• Considerably more of Swisscom's (representative for Public Providers) sites have reached their limit. • Calculations were made for FRMCS in the 900 MHz band and for PP in the 3.5GHz band on the Nyon – Lausanne – Martigny line
Feasibility of FRMCS with 1.9 GHz	• Initial analysis shows that the 5MHz blocks (1900 – 1905 / 1905 – 1910) are suitable with our current site distances (3km on average). • Using these two blocks, redundant coverage could be provided from the same masts, assuming that the rail companies were to be granted the use of both blocks

Table 1: Phase 1 conclusions

4.3 Conclusions after the 2nd phase

The 2nd phase considered some of the topic areas from the 1st phase in greater depth and, in addition, examined new topics.

Work package	Conclusion

Detailed FRMCS study into 900 and 1900 MHz bands	• This study is the most important element of the current feasibility study. It will, therefore, be described in detail. Aim:
	• To analyse and describe the procedure for ascertaining the maximum permissible transmission power under the various scenarios, taking all influencing factors into consideration.
	• To analyse their suitability for an FRMCS radio network measured against the performance factors of data throughput and inter-site distance under different cell loads (normal, high, very high):
	  ○ Scenario 1: 918-921 MHz/3 MHz bandwidth, 19.5 dBm EIRP
	  ○ Scenario 2: 919.3-920.7 MHz/1.4 MHz 27.8 dBm EIRP
	  ○ Scenario 3: 1900-1905 MHz/5 MHz 43 dBm EIRP
	  ○ Scenario 4: 1905-1910 MHz/5 MHz 30 dBm EIRP
	  ○ Scenario 5: 918-923 MHz/5 MHz 21.7 dBm EIRP
	• Main findings from the study
	  ○ Variants 1 and 5 assume a reduction in the number of GSM-R carriers and that the GSM-R network is planned anew.
	  ○ The greatest distance of approx. 5km between cells is possible under Variant 3. The present distances between cells (i.e. 3 km on average) are still possible under this variant with data rates of 3 Mbit/s.

Work package	Conclusion
	○ With greater data rates (5 Mbit/s), only Variant 5 reaches acceptable "inter-site distance" values of approx. 2 km. • The study's recommendations: ○ The most suitable variants are those with the greatest possible transmission power and reception capacity because 1. The best possible solution with respect to transmission performance and inter-site distance can be achieved. 2. the network can be constructed with simpler radio technology since amplifiers in the radio units are dependent on transmission power. • **SBB Telecom's conclusions:** ○ Variants 1 and 5 are not suitable for parallel operation of GSM-R and FRMCS since the restriction for GSM-R is not acceptable. ○ Only Scenarios 3 and 4 suit FRMCS for parallel operation because only they are sufficiently capable without any restriction on GSM-R and because the scope for solutions for high availability coverage (redundancy) is greater.
FRMCS and the data transport network	• The extent to which an existing modern data transport network such as SBB's *Datacom-NG* network is suitable for FRMCS (based on 5G technology) was examined because, as things stand at present, the initial FRMCS routes will be set up on a data network of that kind. Conclusion: ○ In principle, a network such as *Datacom-NG* is adequate for taking FRMCS into initial use with the 5G basis functions (static fulfilment or operation and operation without network encryption). ○ A moderate level of investment in additional functions, e.g. for synchronisation, will be necessary. ○ However, as soon as further functions such as dynamic network slicing, orchestrated operation of FRMCS & data network, virtual RAN architectures, further-reaching security functions, etc. become necessary, the present network will have to be replaced. Upgrading the current network would be a huge undertaking and, in all probability, not possible in its entirety. As FRMCS is being rolled out (from 2026), Datacom-NG itself will be in the process of being

Work package	Conclusion
	superseded so it will be possible for any new requirements to be taken into account as the network is replaced. ○ With this overall picture in mind, particular account needs to be taken of the risks associated with the parallel rollout of the successor to Datacom-NG and of FRMCS.
Core network	• The most suitable solution, as regards the requirements for a highly integrated rail communication platform, is a dedicated FRMCS solution based on a 5G core network, provided that the rail companies have their own FRMCS 5G frequency range. • The timetable depends largely on standardisation. The first European trials will probably base on UIC's Functional- and System Requirement Specification (FRS/SRS) Version 2.0 and can be expected from 2023. An initial procurement on this basis with an upgrade to the target version is, from today's perspective, a viable route for SMARTRAIL 4.0 and SBB as system leader to take. • The scope of FRMCS as the replacement for GSM-R: ○ 3GPP 5G Core ○ 3GPP Mission Critical Service Function (MCx) ○ 3GPP IP Multimedia Subsystem (IMS) function as the pre-requisite for MCx and interworking ○ Interworking Function (IWF) for interworking with GSM-R ○ Additional application servers for railway services which are not included in the scope of the FRMCS User Requirement Specification (URS 4.0) but which remain a rail operations requirement. The aspects listed below, and others, still need to be analysed in greater depth before the concept can be regarded as finalised. ○ FRMCS interworking with GSM-R ○ Integration and migration of the current Value-Added Services (VAS) ○ Voice Group Communication ○ FRMCS interworking with Fixed Terminal Services

Table 2: Phase 2 conclusions

5 Contents and conclusions from Phase 3

Aspects in connection with FRMCS which had previously only received insufficient consideration were analysed in greater detail in this final phase.

The analysis mainly concentrated on solution scenarios for providing very widely available coverage for train paths. The four basic technical scenarios, developed from the solution space of the network sharing sub-project, formed the based for the analysis. The scenarios were "All SBB", "Site Sharing "plus" ", "Multi Operator Core" and "Mobile Virtual Network Operator".

Using this solution space, FRMCS network architectures with various redundancy solutions were sketched and assessed. As regards technical system matters "Site Infrastructure Sharing" variants have no significance and will always be possible to apply. Hence this type of sharing wasn't included in this investigation. However, the "NW Access Sharing" variant was included in addition.

The aim of the study is to ensure that only feasible and effective variants for providing an FRMCS signal along the rail network are pursued by SR4.0.

Based on the Ericsson final feasibility study report concerning the topics listed below, the FRMCS study team consisting of smartrail 4.0 und SBB Telecom members examined in a further process three main goals (see chapter 5.1) with respect to trackside deployment architecture.

- Network sharing scenarios
- 3GPP RAN Features
- Network Assumptions
- Radio Network Redundancy
- Link Budget Study
- Simulations
- Overview of 5G Core Network
- Meeting the Requirements of 3GPP TS 22.289

5.1 Main objectives

FRMCS Trackside - Deployment Architecture for Critical Communication support i.e. 3GPP radio deployment based on performance results (Extraction from Ericsson report of Phase 3)

Goal 1: 'Inter-site distance for main tracks, secondary tracks and stations/intersections considering SBB traffic estimation, 5G NR system limits and potential spectrum availability (i.e. 900MHz and 1900MHz).

Goal 2: Assign 3GPP radio access deployment options to potential "Availability Categories": Fault Tolerant, High Available and Best Effort.

Goal 3: Develop deployment scenarios from Goals 1 & 2 for a Railway Infrastructure Manager (IM) only approach and an IM+PMNO approach.

5.2 Overview Radio link simulation

The following table is an extract from the Ericsson report "radio link simulation" considering 5G NR FDD/TDD (worst case scenario consideration)

Throughput at cell edge (NR 900 MHz / CBW 5 MHz / EIRP 59.7 dBm / UE Tx Power 23 dBm / Very high utilization)	Antenna height 22 m	Antenna height 16 m
ISD (@throughput 1 Mbps)	11.69 km	9.76 km
ISD (@throughput 3 Mbps)	7.74 km	6.53 km
ISD (@throughput 5 Mbps)	6.00 km	5.10 km
Throughput at cell edge (NR 1900 MHz / CBW 5 MHz / EIRP 30 dBm / UE Tx Power 23 dBm / 50:50 / Very high utilization)	Antenna height 22 m	Antenna height 16 m
ISD (@throughput 1 Mbps)	3.60 km	3.10 km
ISD (@throughput 3 Mbps)	2.59 km	2.26 km
ISD (@throughput 5 Mbps)	1.60 km	1.41 km
Throughput at cell edge (NR 1900 MHz / CBW 10 MHz / EIRP 40 dBm / UE Tx Power 23 dBm / 50:50 / Very high utilization)	Antenna height 22 m	Antenna height 16 m
ISD (@throughput 1 Mbps)	5.09 km	4.35 km
ISD (@throughput 3 Mbps)	3.36 km	2.90 km
ISD (@throughput 5 Mbps)	2.59 km	2.25 km
ISD (@throughput 10 Mbps)	1.42 km	1.25 km

Table 3: Intersite Distance (ISD) based on Ericsson simulation and throughput assumptions

5.2.1 Main uncertainties applicable for all simulations

- DL/UL coverage limitations as a prerequisite are not known
- Uplink power control for TDD mode operation (fractional power control: e.g. path-loss compensation factor α) not known
- EVA70 (MATLAB) was assumed by Ericsson, but this may not accommodate train speeds up to 250km/h and does not consider real radio propagation conditions for all radio coverage requirements. Hence, some margins need to be considered in the selection of the ISD.

5.3 Findings based on performance results

Factors that may have limiting effects

- Inter Site Distance
- Antenna height (22 m / 16 m)
- Channel bandwidth (10 MHz / 5 MHz)
- Uplink Throughput at cell edge (1 Mbps / 3 Mbps / 5 Mbps / 10 Mbps)

5.3.1 Applicability for FRMCS

Simultaneous operation of GSM-R/FRMCS and of stand-alone operation FRMCS were considered.

	874.4-880/919.4-925 MHz (FDD)	1900-1910 MHz (TDD)
Simultaneous operation of GSM-R/FRMCS	Only applicable for GSM-R	Applicable for 5G NR
FRMCS stand-alone operation	Applicable for 5G NR (see Note)	Applicable for 5G NR

Table 4: Applicability for FRMCS

Note: SBB focus is on 5G NR. At regional level (Europe) only 5.6MHz@900MHz will be harmonised

- Due to current channel bandwidth restrictions (assuming 5.6 MHz in 900 MHz) in 5G NR a joint use of the 900 MHz frequency spectrum for GSM-R and FRMCS is not feasible.
- For simultaneous operation of GSM-R and FRMCS the focus for FRMCS is on 5G NR 1900 MHz only.
- For the FRMCS stand-alone operation, all spectrum options are available.

5.4 Inter Site Distance (Site Grid) estimation

Assumptions

- The following table is based on the extract from the Ericsson report FSP3 and the corresponding modelling uncertainties are indicated.
- The cell edge throughput is the constraining factor for Inter Site Distance determination.
- The categories 1 / 3 / 5 / 10 Mbps of cell edge throughput were defined for simplicity reasons for the radio link simulation and may not represent the exact SBB traffic estimates.
- **The consolidated SBB traffic estimates are considered here. They were not available at the time of the Ericsson estimate.**
- The resulting ISD based on Ericsson's radio link simulation is considered as a first estimation with a UE power class 3 corresponding to 23 dBm.
- As soon as the ETSI TC RT (ETSI Technical Committee Rail Communication) radio system simulation is published, the ISD will be reassessed.

Summary Traffic calc	Single Track	Multi Track	Small Station	Main Station	Shunting Yard
UL Critical [Mbps] ↳ Row 1a	0.66	1.11	1.12	5.48	2.76
DL Critical [Mbps] ↳ Row 1b	0.64	1.04	1.06	5.18	2.70
Resulting ISD [km] (based on Cell Edge Throughput) ↳ For rows 1a, 1b	3.10-4.35 @16m 3.60-5.09 @22m 1900MHz (5 MHz CBW)	2.26-2.90 @16m 2.59-3.36 @22m 1900MHz (5 MHz CBW)	2.26-2.90 @16m 2.59-3.36 @22m 1900MHz (5 MHz CBW)	1.25km @16m 1.42km @22m 1900MHz (10 MHz CBW)	1.41-2.25 @16m 1.60-2.59 @22m 1900MHz (5 MHz CBW)
UL Critical + Performance [Mbps] ↳ Sum of rows 1a+2a	1.07	1.92	1.95	9.55	4.49
DL Critical + Performance [Mbps] ↳ Sum of rows 1b+2b	1.33	2.42	2.49	12.63	5.03
Resulting ISD [km] (based on Cell Edge Throughput) ↳ For rows 1a+2a, 1b+2b	2.26-2.90 @16m 2.59-3.36 @22m 1900MHz (5 MHz CBW)	2.26-2.90 @16m 2.59-3.36 @22m 1900MHz (5 MHz CBW)	2.26-2.90 @16m 2.59-3.36 @22m 1900MHz (5 MHz CBW)	1.25km @16m 1.42km @22m 1900MHz (10 MHz CBW) + 900MHz (2x5 MHz CBW)	1.25km @16m 1.42km @22m 1900MHz (10 MHz CBW)
UL Critical + Performance [Mbps] ↳ Sum of rows 1a+2a+3a	2.32	3.17	5.70	22.05	31.99
DL Critical + Performance [Mbps] ↳ Sum of rows 1b+2b+3b	1.33	2.42	4.99	22.63	30.03
Resulting ISD [km] (based on Cell Edge Throughput) ↳ For rows 1a+2a+3a, 1b+2b+3b	2.26-2.90 @16m 2.59-3.36 @22m 1900MHz (5 MHz CBW)	1.41-2.25 @16m 1.60-2.59 @22m 1900MHz (5 MHz CBW)	1.25km @16m 1.42km @22m 1900MHz (10 MHz CBW)	1.25km @16m 1.42km @22m 1900MHz (10 MHz CBW) + 900MHz (2x5 MHz CBW) + additional CBW	1.25km @16m 1.42km @22m 1900MHz (10 MHz CBW) + 900MHz (2x5 MHz CBW) + additional CBW

Table 5: Intersite Distance based on effective SR4.0 traffic requirements

Note: Grade of Automation - GoA 3/4 requires additional Carrier Bandwidth due to high traffic volume estimates!

5.5 Generic deployment consideration (system view)

5.5.1 Targets and requirements

- Ensuring availability and maintainability
- Elimination of all SPOF
- Communication session recovery must not exceed 3 seconds for some critical applications (Input SR4.0)

5.5.2 Assessment by SBB of deployment scenarios

For line coverage purposes the following scenarios based on Ericsson's proposal were further assessed by SBB.

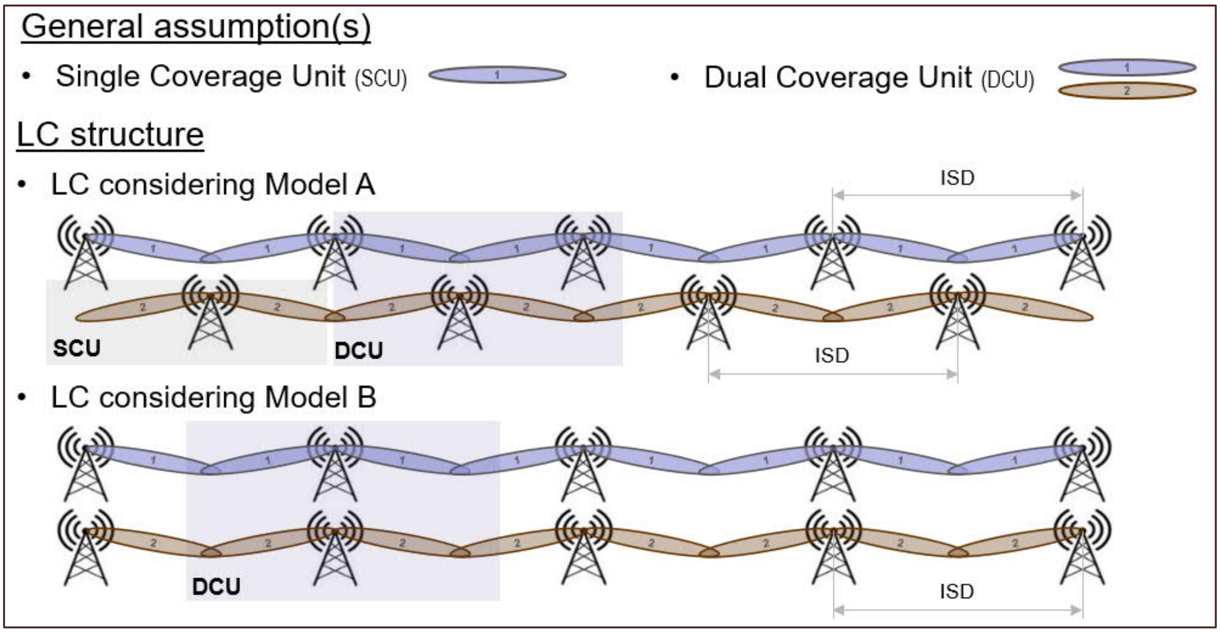

Figure 1 Deployment models for line coverage

Based on the above scheme, the following variants were defined and assessed.

Model	Spectrum range of	DC	CA	CUT	SPOF elimination	Function	Availability	UE-T
A	**(A-1)** 900MHz (5MHz)	n/a	n/a	SCU	No	n/a	BE	[1], [2]
	(A-2) 900MHz (5+5MHz)	n/a (Note 4)	n/a (Note 4)	DCU	Yes	FFR/CoMP	FT	[1], [2]
	(A-3) 1900MHz (10MHz)	n/a	n/a	SCU	No	n/a	BE	[1], [2]
	(A-4) 1900MHz (10+10MHz)	n/a (Note 4)	n/a (Note 4)	DCU	Yes	FFR/CoMP	FT	[1], [2]
	(A-5) 1900MHz (5+5MHz)	Yes (Note 1)	Yes	DCU	Yes	Non-CoMP	HA	[1], [2]
	(A-6) 900MHz (5 MHz) & 1900MHz (10 MHz)	Yes	Yes	DCU	Yes	Non-CoMP	FT	[1], [2]
	(A-7) 900MHz (5 MHz) & 1900MHz (10 MHz)	Yes	Yes	DCU	Yes	CoMP (Note 3)	FT	[1], [2]
B (Note 5)	**(B-2)** 900MHz (5+5MHz)	n/a (Note 4)	n/a (Note 4)	DCU	Yes	FFR	HA	[1], [2]
	(B-4) 1900MHz (10+10MHz) (Note 2)	n/a	n/a	DCU	Yes	FFR	HA	[1], [2]
	(B-5) 1900MHz (5+5MHz)	Yes (Note 1)	Yes	DCU	Yes	Non-CoMP	HA	[1], [2]
	(B-6) 900MHz (5 MHz) & 1900MHz (10 MHz)	Yes	Yes	DCU	Yes	Non-CoMP	FT	[1], [2]
	(B-7) 900MHz (5 MHz) & 1900MHz (10 MHz)	Yes	Yes	DCU	Yes	CoMP (Note 3)	FT	[1], [2]

Note 1: Only theoretical option (implementation depended) and may require two independent band numbers for the same spectrum part.
Note 2: May be further improved with the use of NOMA that is FFS in 3GPP.
Note 3: The use of CoMP may be potentially applied to a single or both duplex mode of operations.
Note 4: CA and DC are not applicable due to spectrum limitations!
Note 5: Potential option B-1 and B-3 are equivalent to A-1 and A-3 .

Table 6: Solution space IM only line coverage trackside deployment

With respect to the following assessment criteria, variant A-4 and B-5 achieved the highest score

Operation	Intervention Time; Service Impact (Risks); Customer Impact (n/a for global concept); Operational Complexity (n/a for global concept); Life Cycle Management; Know-how Operational Staff (n/a for global concept)
Technology	Availability Coverage Unit; Signal Quality; Technical Complexity)

Table 7:Criteria for assessment of deployment variants

5.6 Spectrum Enhancement Consideration

5.6.1 Rationale in the IM context

The use of some applications according to SBB´s traffic estimate may exceed the system's own IM spectrum resources (1900MHz for simultaneous operation of GSM-R/FRMCS and after coexistence phase of GSM+FRMCS both spectres 900+1900MHz).

Note: It is assumed that SBB fronthaul/backhaul transmission resources are sufficient.

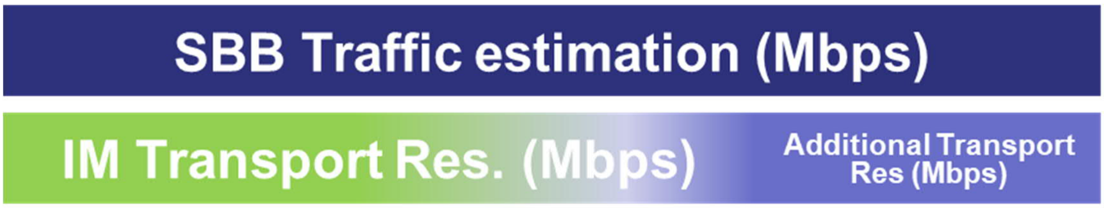

Figure 2: Relationship of traffic estimation and transport capacity

Conclusion: Additional spectrum resources may be required.

The results of the feasibility study partly influenced the options for adding additional spectrum resources to a FRMCS solution.

5.6.2 Potential additional spectrum resources (Spectrum Enhancement Option)

SEO-0	Additional licensed spectrum dedicated to the IM (e.g. 2300MHz) for nationwide availability or potential use of unlicensed spectrum (i.e. 3GPP LAA) in the context with 5G NR (limited to non-interoperable railway operating points).
SEO-1	Unlicensed spectrum: allocated to non-3GPP access in designated areas (Non-3GPP access is required for interoperability) / (provides limited mobility).
SEO-2	Allocated licensed spectrum of one or multiple PMNOs, to provide nationwide availability.

Table 8 3 types of spectrum enhancement options

The Option "SEO-2" with four types of sub-scenarios will be reflected for further consideration at this point since the two other types are considered not to be realistic at the current state of planning.

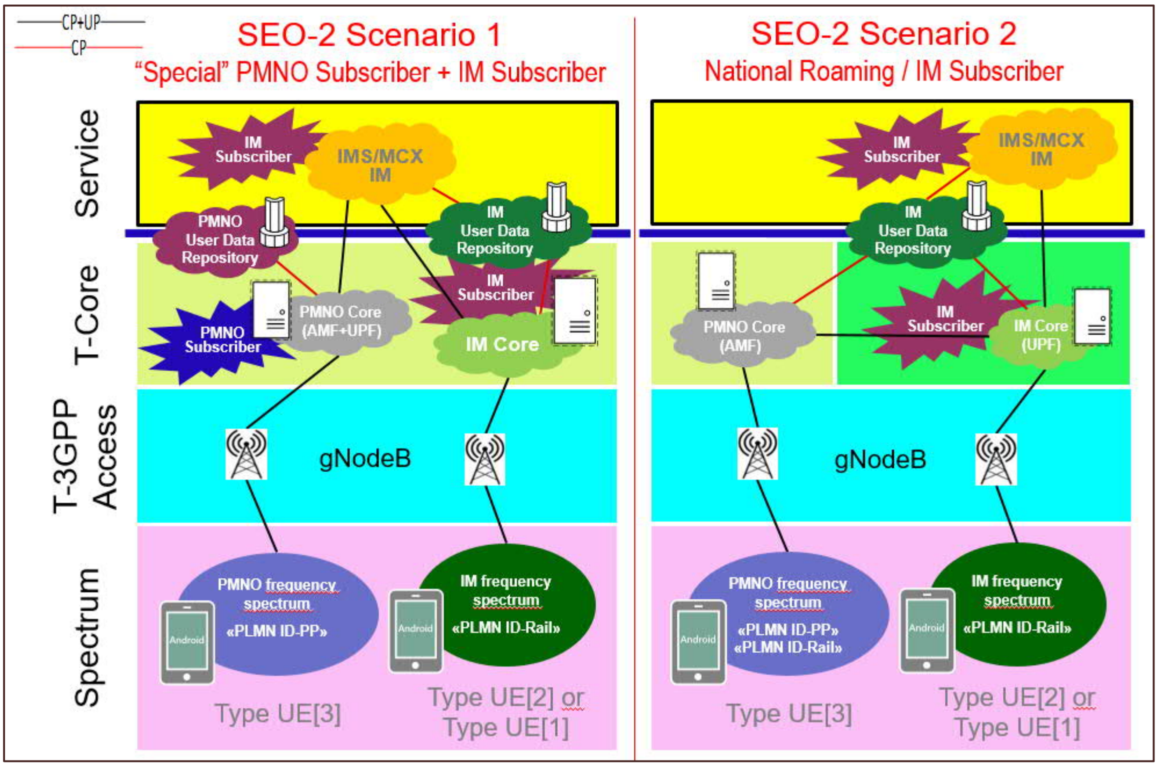

Figure 3: Scenario "IM & PMNO subscriber access to IM FRMCS" and national roaming

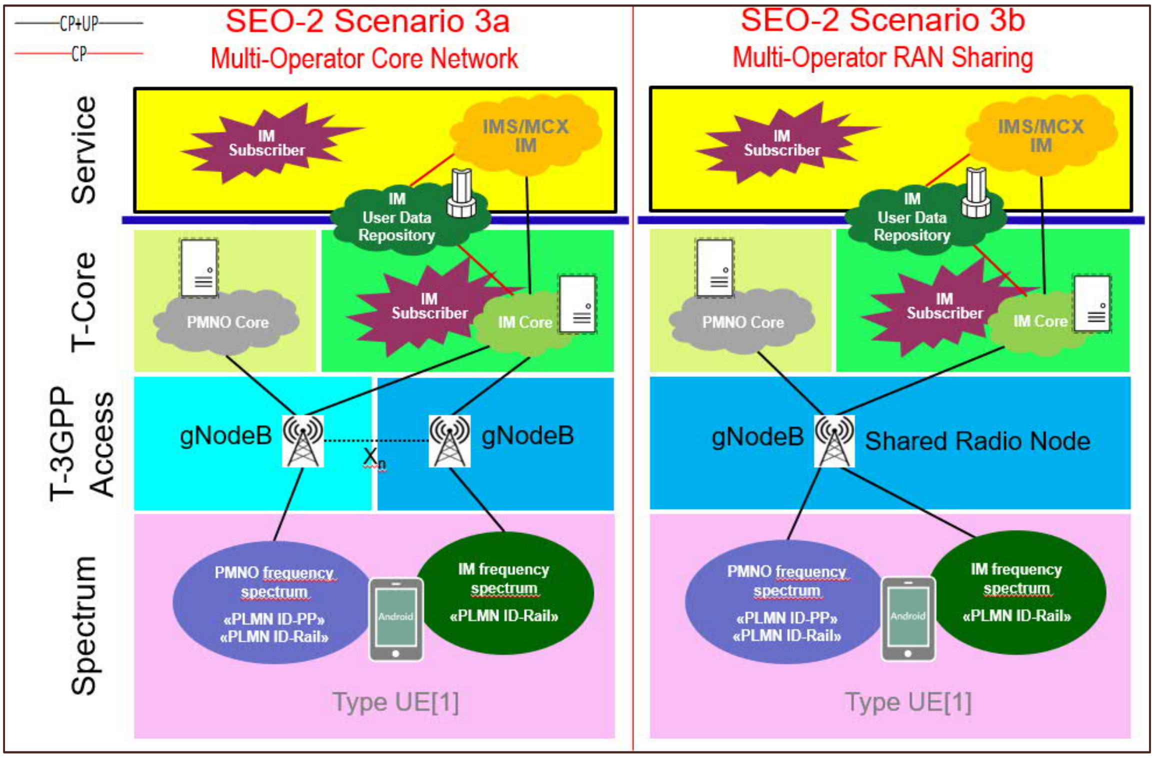

Figure 4: MOCN and MORAN sharing scenarios

In combination with “Table 6: Line Coverage Deployment Variants”, additional coverage solutions for trackside deployment were outlined briefly.

Model	Spectrum range of	DC	CA	CUT	SPOF elimination	Function IM/PMNO	Availability	UE-T (Note 4)
A (Note 6)	**(A-1/A-3) S-1** + PMNO (Note 2)	n/a	Yes (PMNO only)	DCU	Yes (Note 1)	n/a (Note 1)	HA (Note 1), (Note 5)	[1], [2]+[3]
	(A-1/A-3) S-2 + PMNO (Note 2)	n/a	Yes (PMNO only)	DCU	Yes (Note 1)	n/a (Note 1)	HA (Note 1), (Note 5)	[1], [2]+[3]
	(A-1/A-3) S-3a + PMNO (Note 2)	Yes (Note 3)	Yes (PMNO only)	DCU	Yes (Note 1)	n/a (Note 1)	HA (Note 1), (Note 5)	[1]
	(A-1/A-3) S-3b + PMNO (Note 2)	n/a	Yes (PMNO only)	DCU	Partially (Note 5)	n/a (Note 1)	Potential HA (Note 5)	[1]
	(A-4) S-1 1900MHz IM (10+10MHz) + PMNO	n/a	Yes (PMNO only)	DCU	Yes (Note 1)	IM: FFR/CoMP (Note 1)	FT (Note 1), (Note 5)	[1], [2]+[3]
	(A-4) S-2 1900MHz IM (10+10MHz) + PMNO	n/a	Yes (PMNO only)	DCU	Yes (Note 1)	IM: FFR/CoMP (Note 1)	FT (Note 1), (Note 5)	[1], [2]+[3]
	(A-4) S-3a 1900MHz IM (10+10MHz) + PMNO	Yes (Note 3)	Yes (PMNO only)	DCU	Yes (Note 1)	IM: FFR/CoMP (Note 1)	FT (Note 1), (Note 5)	[1]
	(A-4) S-3b 1900MHz IM (10+10MHz) + PMNO	n/a	Yes (PMNO only)	DCU	Partially (Note 5)	IM: FFR/CoMP (Note 1)	FT (Note 1), (Note 5)	[1]

Note 1: From IM point of view PMNO setup is uncontrolled!
Note 2: Scenarios are similar except the used spectrum blocks see table IM only approach. A1 corresponds to 900MHz@5MHZ and A3 corresponds to 1900MHz@10MHz.
Note 3: Theoretical option (implementation dependent) which requires the use of Xn interface across physical or logical radio networks.
Note 4: The simultaneous use of IM and PMNO requires at least two independent UEs and corresponding traffic association.
Note 5: Potential implementation options to decouple functions and transceivers co-siting with PMNO are FFS.
Note 6: S stays for “Scenario”.

Table 9: solution space IM & PMNO trackside coverage

At the current state of the project and given the technical basis, a sound assessment and rating of these principally realisable variants is not yet possible. This depends on subsequent work on smartrail 4.0. But an initial, non-exhaustive list of possible risks and limitations has been compiled.

5.6.3 Conditions / potential risks for operation with PMNO RAN (non-exhaustive)

- A mixed PMNO/IM approach considers the possibility of how to improve the availability when IM spectrums resources are limited. The consideration encompasses the scenarios that may improve best effort behaviour. To complete the picture, the A4 scenario (1900MHz (10+10MHz)) has been considered too because PMNO is a potential fallback for double failure.
- PMNO supports the use of Access Category for the IM subscriber as part of IMS MPS to gather preferred signalling resource allocation already during the access phase.
- PMNO support 5G standalone approach!
- Means of interference mitigation, i.e. fractional use of spectrum or CoMP, is assumed, otherwise it may cause significant throughput drops mainly at cell edge.
- PMNO RAN supports train speed up to 250km/h + margin.
- Impact of Beamforming/eMIMO, e.g. in association with CoMP to a line coverage approach is for further study.
- Backhaul and fronthaul transmission is not considered at this stage.

- The PMNO Life Cycle Management is determined by frequent SW updates driven by new services. This will cause a significant increase in testing effort for the IM!
- The scope of the tests and resulting testability depends on vendor strategy (single/multiple vendor).
- All SEO-2 options assume an IM service subscription!
- SEO-2 Option 1: Independent transport subscriptions (IM and PMNO) are required!
- SEO-2 Option 2, 3a, 3b: Only IM transport subscription is required!
- The use of the SEO-2 option does not prevent the simultaneous use of the SEO-0 and SEO-1 option.
- The potential use of traffic isolation and efficient local radio, e.g. slicing, is not considered at this stage!

1 Conclusion

The feasibility study conducted in the beginning by both Ericsson and Swisscom and after the 1st. phase only by Ericsson is a good baseline for verifying the initial hypothesis of “smartrail 4.0 connectivity” with respect to FRMCS based on 5G. It quite strongly influenced smartrail 4.0 work with respect to all three goals.

Goal 1: ‘Inter-site distance for main tracks, sidetracks and stations/intersections considering SBB traffic estimates, 5G NR system limits and potential spectrum availability (i.e. 900MHz and 1900MHz).

Goal 2: Assign 3GPP radio access deployment options to potential “Availability Categories” which are Fault Tolerant, High Available and Best Effort.

Goal 3: Develop deployment scenarios from Goals 1 & 2 for a Railway Infrastructure Manager (IM) only approach and an IM+PMNO approach.

The results provided by Swisscom and Ericsson during this feasibility study serve as valuable input in preparation for the variant proposal to be submitted to the Federal Office of Transport. However, further investigations are required that have to be performed by the railways on their own – potentially supported by supplier-neutral consultancy services.

Note also that aside from an IM only solution and an IM + PMNO solution as considered above, a deployment scenario based on PMNO transport resources only shall also be possible (mainly for but not necessarily limited to secondary lines).

6 Lists

6.1 List of tables

6.2 List of illustrations

6.3 List of references

Ref No.	Title of reference	Link (SBB Sharepoint)
[REF 1]	SBB_WP2.1_Executive_summary_RevB	https://sbb.sharepoint.com/:b:/r/sites/sr40-con/Freigegebene%20Dokumente/General/310%20-%20Subsystem%20-%20Mobilfunknetz%20(FRMCS)/71%20-%20Feasibility/Publikation/Final%20Documentation%20Ericsson/SBB_WP2.1_Executive_summary_RevB.pptx.pdf?csf=1&web=1&e=874YP2
[REF 2]	SBB_Phase_3_Final_slides_RevB_pdf	https://sbb.sharepoint.com/:b:/r/sites/sr40-con/Freigegebene%20Dokumente/General/310%20-%20Subsystem%20-%20Mobilfunknetz%20(FRMCS)/71%20-%20Feasibility/Publikation/Final%20Documentation%20Ericsson/SBB_Phase_3_Final_slides_RevB_20200429.pdf?csf=1&web=1&e=TaeW7V

6.4 Abbreviations and definitions

Abbreviation	Definition / description
3GPP	The "3rd Generation Partnership Project" is a global collaborative partnership of standardisation committees for the purpose of standardising mobile phone communications; specifically for UMTS, GERAN, LTE and NGN. 3GPP was established on 4 December 1998 by five "Organisational Partners".
5G-NR	"5G NR (New Radio)" is a new Radio Access Technology (RAT), developed by 3GPP for the 5G (fifth generation) mobile phone network. It was developed as the global standard for the air interface between 5G networks.
AINET	The successor network to SBB Datacom NG
ATO	"Automated Train Operation" consists of 5 automation levels (GoA 0 - GoA 4).
CCS	Control, Command and Signalling. These terms include all those items of equipment which are necessary to ensure safety and to manage and monitor movements by trains which are entitled to run on the network.
CoMP	Coordinated Multi Point
DL/UL	Downlink / Uplink
eMIMO	enhanced Multiple Input Multiple Output
EPC	Evolved Packet System (EPS) is the term used to describe the architecture of the LTE mobile radio standard. It includes the core network (Evolved Packet Core, EPC), the radio communications networks (E-UTRAN), the end user terminals (UE) and the services. EPS is based entirely on packet switching and is thus fundamentally different from the older UMTS and GSM technologies which still use circuit switching. Nonetheless, LTE is compatible with these technologies and can be operated in parallel with them.
ERA	European Union Agency for Railways
ETSI TC RT	European Telecommunications Standards Institute Technical Committee Rail Communication
FDD	Frequency Division Duplex
IM	Infrastructure Manager
ISD	Inter Site Distance
GPRS	General Packet Radio Service is a "General Packet-Oriented Radio Service"; it is the term used to describe the data transmission service in GSM networks.
GSM-R	Global System for Mobile Communications - Rail
LC Structure	Line Coverage Structure
PMNO	Public Mobile Network Operator
RAN	Radio Access Network
TDD	Time Division Duplex
SEO	Spectrum Enhancement Option
TOBA	Telecom On-Board Architecture
TSI	The TSI are those Technical Specifications for Interoperability which are to be applied. They are technical regulations having the force of law, which were laid down by the European Commission for Europe-wide interoperable railway traffic.
UIC	The UIC (French for Union internationale des chemins de fer) is

	an international association of railway undertakings.